DEVELOPMENT AND TESTING OF AN ACOUSTIC SYSTEM FOR <u>IN SITU</u> DETERMINATION OF MICROBUBBLE CONCENTRATION IN THE OCEAN

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THESIS

Development and Testing of an Acoustic System for In Situ Determination of Microbubble Concentrations in the Ocean

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
June 1971

ABSTRACT

The effect of bubbles on sound propagation in the ocean has long been known. More recently, bubbles rising to the ocean surface have been related to salt nuclei in clouds. Yet due to the lack of suitable instrumentation little data are available on the concentration of bubbles in the ocean. A one-dimensional standing wave system was constructed and evaluated to determine bubble concentrations by measuring the effect of bubbles on the system damping constant (Q^{-1}). The system was comprised of a mylar electrostatic transducer built into a plane reflector facing a parallel reflecting plate, and associated electronic components. The system was designed to measure bubbles of radius from approximately 500 microns to 30 microns utilizing frequencies from 20 to 100 kHz at depths to 30 meters. The system accuracy was determined to be ± 10Hz in resonant bandwidth corresponding to 500 bubbles/m^3 at 67 kHz. The system was used to successfully measure bubbles in a laboratory tank.

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Herman Medwin for his guidance and patience during the preparation of this thesis and to Mr. William Smith for his assistance in the construction and maintenance of equipment.

I. INTRODUCTION

The process of scattering and absorption of sound energy by air bubbles in water is well known. However, except for bubbles observed in ship wakes or in the surf zone, little is known about the presence and persistance of bubbles at sea. Although there has been some notable work done in the laboratory concerning bubble action in the water, there have been very few attempts to make "in situ" measurements of bubbles at sea. Until 1964, when work commenced at the Naval Postgraduate School to develop a system to measure bubbles at sea, there were no suitable instruments to determine bubble concentrations at sea. The acoustic system used in this project was basically developed from projects starting in 1964 [2,3,4].

A knowledge of bubble concentrations in the ocean is important for reasons other than their effect on sound propagation. A bubble in water is a cavitation nucleus. As it rises to the surface, it collect particulate matter and chemicals in solution, and when it bursts at the surface, it produces airborne salt nuclei which can be linked to thunderstorm activity [1]. The particulate matter and organic skin may form surface slicks, which in turn could be evidence of the mechanism which produced the bubbles in the first place, such as plant and animal life or possibly internal waves and chemical processes in the sea. Therefore, a greater knowledge of ocean bubbles could lead to a greater understanding of other ocean processes. This project was undertaken to provide suitable instrumentation to gather "in situ" data on bubble concentrations at sea.

II. BUBBLE THEORY

Classical theory suggests that bubbles have only a transitory existence in water and last only long enough to rise to the surface or diffuse into the surrounding water. However, experiments have shown that small bubbles may remain stabilized in the water for long periods of time. Experiments have indicated that bubbles of radii less than about 30 microns may remain suspended indefinitely, and bubbles have been observed to persist for over 100 hours [8].

Several bubble stabilization models have been proposed to explain the persistence of microbubbles, but none satisfy all conditions. However, in the bubble sizes of interest in this research, (30-500 micron radius) the compressed wall model provides the most satisfactory explanation for bubble stabilization. In this model, when a bubble is formed in the water, it begins to capture solid particles. At the same time the bubble shrinks by diffusion of gas into the surrounding water. The bubble continues to collect particles and to shrink in size until a continuous wall of particles is formed around the bubble. This wall would be capable of supporting a compressive stress, thereby maintaining the bubble size. Gas would continue to diffuse out of the bubble until the bubble's internal pressure equaled that of the partial pressure of gases in the surrounding water. The mass of the particles forming the bubble's wall would supply counter buoyancy to the bubbles [8]. In this manner, bubbles could attain various degrees of stability in the water column.

III. ACOUSTIC THEORY

A gas bubble, because of its elasticity and effective mass, forms a resonant system which are able to scatter and absorb sound to a much greater degree than its geometrical size would indicate. The scattering cross section for a single bubble is [5]:

$$\sigma_s = \frac{\text{power scattered}}{\text{Incident acoustic intensity}} = \frac{4\pi a^2}{\left[\left(\frac{\omega_o}{\omega}\right)^2 - 1\right]^2 + \delta^2} \qquad (1)$$

The absorption cross section is given by:

$$a = \frac{\text{power absorbed by bubble}}{\text{Incident acoustic intensity}} = \sigma_s \left(\frac{\delta}{k_o a} - 1\right) \qquad (2)$$

and the extinction cross section is defined as the sum of (1) and (2):

$$\sigma_e = \sigma_a + \sigma_s \qquad (3)$$

where:

a = resonant bubble radius

ω_o = resonant angular frequency of bubble pulsation

ω = angular frequency of incident sound

δ = bubble damping constant

$k_o = \frac{2\pi}{\lambda_o}$ = wave number at resonant frequency.

The resonant frequency for a clean air bubble in water is given by [5]:

$$f_o = \frac{1}{2\pi a} \left(\frac{3\gamma p}{\rho} \frac{\tau}{a}\right)^{\frac{1}{2}} \qquad (4)$$

Rearranging terms and noting that $f = c/\lambda$ and $k = 2\pi/\lambda$ gives:

$$ka = \left(\frac{3\gamma p}{\rho} \frac{\tau}{a}\right)^{\frac{1}{2}}$$

where:

γ = ratio of specific heats of bubble gases

p = ambient pressure at bubble depth

ρ = density of surrounding water

τ = surface tension factor.

The factor τ is very nearly unity for bubble sizes of interest in this study, and the quantity γ/a is in the range $1.6 < \gamma a^{-1} < 1.40$ for bubbles greater than 20 microns. Using these values and representative values for the ambient pressure and water density, the value of ka is on the order of 10^{-2}. Thus, using equations (1) and (2) and taking into account the value of ka, the expression for the extinction cross-section of a bubble is given by:

$$\sigma_e = \frac{4\pi a}{k} \Big/ [(\frac{f_o}{f})^2 - 1]^2 + \delta \tag{5}$$

At resonance, equation (5) reduces to:

$$\sigma_{e_o} = \frac{4\pi a}{k_o \delta} \tag{6}$$

Since:

$$k_o = \frac{2\pi}{\lambda_o} = 2\pi \frac{f_o}{c}$$

$$\sigma_{e_o} = \frac{2ac}{f_o \delta}$$

where c = velocity of sound in water, m/sec.

A 150 micron bubble has a resonant frequency of approximately 25 kHz. at the water surface (Figure 1). Using c = 1500 m/sec and δ = .07 (from Figure 2), the resonant extinction cross-section for this bubble would be 2.58 cm^2. This represents an acoustical cross-sectional area 3650 times the geometrical cross-sectional area. In comparison, a rigid scatterer of the same size would have an acoustic extinction

cross-sectional area at most equal to the geometrical cross-section and at the bubble's resonant frequency would have an acoustic cross-sectional area 10^{-8} times its geometric cross-secional area [5]. Therefore it can be assumed that sound attenuation by solid particles can be ignored.

Because of the large acoustic cross-section of bubbles, acoustic measuring techniques have to date proven to be the most practical. Three assumptions are necessary in order to determine bubble concentrations acoustically. First, it is assumed that particulate matter forming the bubble wall has a negligable effect on the extinction cross-section; second, the bubble gases are assumed to be the same as atmospheric air; and third, it is assumed that all sound attenuation at a given frequency is due to bubbles of resonant size [5].

IV. THEORY OF ACOUSTIC MEASUREMENTS

When an acoustic signal is transmitted between two rigid, parallel reflectors, a standing wave will be established if the spacing of the two reflectors is an integer multiple of a half wavelength for a given frequency (Figure 3). This can be expressed as:

$$L = \frac{n\lambda}{2} \quad n = 1, 2, 3, \ldots. \tag{8}$$

where:

L = spacing between plates.

If the plates are fixed in position, the resonant frequencies for a given plate spacing is given by:

$$f_n = \frac{nc}{2L} \quad n = 1, 2, 3, \ldots \tag{9}$$

where:

$$f = \frac{c}{\lambda} .$$

The efficiency with which a resonant system stores energy is termed the "quality factor", Q. The Q may be expressed as [4]:

$$Q = \frac{f_0}{\Delta f} \tag{10}$$

where:

f_0 = resonant frequency in Hz

Δf = half power bandwidth in Hz,

or by:

$$Q = \frac{\pi}{\alpha\lambda} \tag{11}$$

where:

α = spatial attenuation, nepers/m

λ = wavelength at the resonant frequency.

When bubbles are present, the system will not be as efficient in storing energy; therefore, the system Q will be lower. By comparing the system Q in bubble free water and in water with bubbles, the sound attenuation due to bubbles can be determined. If measurements in bubble free water are denoted by the subscript 1 and measurements in water with bubbles are represented by the subscript 2, the attenuation due to bubbles can be bound by rearranging equation (11):

$$\alpha = \frac{\pi}{Q\lambda} .$$

The increase in attenuation due to a bubble is:

$$\Delta\alpha = \alpha_2 - \alpha_1 = \frac{\pi}{\lambda}\left(\frac{1}{Q_2} - \frac{1}{Q_1}\right).$$

Recalling Equation (10):

$$\Delta\alpha = \frac{\pi}{\lambda f_o}(\Delta f_2 - \Delta f_1) \quad \text{nepers/m}$$

Converting to db/m gives:

$$\Delta\alpha = \frac{8.68\pi}{c}(\Delta f_2 - \Delta f_1) \tag{12}$$

$\Delta\alpha$ can be related to the extinction cross-section, σ_e, as [6]:

$$\Delta\alpha = 4.34 n\sigma_e \quad \text{db/m} \tag{13}$$

where n = number of bubbles per cubic meter.

Setting (12) equal to (13) gives:

$$\frac{8.68}{c}(\Delta f_2 - \Delta f_1) = 4.34\, n\sigma_e$$

Solving for n gives the expression:

$$n = \frac{2\pi}{c\sigma_e}(\Delta f_2 - \Delta f_1)$$

Substituting for σ_e from (7) gives the expression for bubble concentrations:

$$n = \frac{\pi f_0 \delta}{c^2 a} (\Delta f_2 - \Delta f_1) \quad \text{bubbles/m}^3 \quad . \tag{14}$$

V. EQUIPMENT DESIGN

The basic design of the standing wave system developed in this project was the result of earlier projects [2,3,4]. However, previous systems either did not give consistant results or failed to give any results at all. In this project, the standing wave system was redesigned and tested to insure reliable performance in the frequency range of interest (20-100 kHz). A block diagram of the entire system is shown in Figure 4. Each block will now be considered separately.

A. SIGNAL GENERATOR

The first oscillator used to provide the input signal to the system was a WAVETEK 114. The WAVETEK was used in the sweep mode with the sweep rate kept below 100 Hz/sec in order to allow the resonant pattern to develop completely [4]. The time sweep of the WAVETEK is linear, provided it is properly warmed up. This oscillator is limited to a maximum sweep time of five minutes, so several runs were necessary to cover the frequency range of interest. To facilitate data taking, an HP3590A Wave Analyzer was used in place of the WAVETEK. The main advantage of the wave analyzer was that it had a sweep time of almost 11 minutes, enabling it to cover the frequency range in one run. In addition, the filter characteristics of the HP3590A eliminated a large part of the interfering noise.

B. POWER AMPLIFIER

The power amplifier used was a HP 467A power amplifier. Its purpose was to increase the signal power applied to the transducer and

provide a more variable output to the transducer for test purposes. A 10 volt peak-to-peak output was commonly used. A larger output caused distortion in the received signal.

C. POLARIZATION

A polarizing voltage of 300 volts DC was applied to the mylar transducer to keep it closely attracted to the transducer back, yet free to oscillate. The level of polarization proved to be very critical to the operation of the system. Polarization will be considered in more detail in Section VI.

D. TRANSDUCER, REFLECTORS AND FRAME

The design of the transducer used in the standing wave system is shown in Figure 5. It consisted of a 30 inch diameter sheet of aluminum coated one mil (0.025 mm.) mylar glued to a 30 inch diameter plexiglass backing. Mounted in the plexiglass was an four inch wide annular ring of aluminum to provide the second electrode for the electrostatic mylar transducer. The mylar was left unglued over the aluminum ring and this ring was the active face of the transducer. Since the mylar transducer operates essentially as a piston transducer, an air slot was provided to maintain an air film between the mylar and the aluminum plate. The air slot provides a degree of pressure equalization when the system is operated at different depths in the sea, preventing the mylar from stretching. Other characteristics of mylar transducers are discussed by Keller [4].

The mylar was coated with approximately a one mm thickness of Shell Epon 828 epoxy resin mixed with 30 percent Shell Epon curing agent by weight for water proofing. Liquid neopreme was added for additional

protection. Water in contact with the aluminum film would cause the film to separate from the mylar, disrupting its transducing ability. Careful handling was necessary so as not to subject the epoxy to shocks which might crack the epoxy and cause water seepage. Rapid exposure to large temperature variations was avoided for the same reasons.

The plexiglass-backed mylar sheet served as one reflector in the standing wave system, while a 30 inch diameter steel plate (one fourth inch thick) served as the second plate. The original design utilized steel plates for both reflectors, since steel has a higher reflectivity than plexiglass, but the plexiglass provided less problems with electrical radiation. Also, the plexiglass proved to be easier to mount and easier to water proof. Mounting a full sheet rather than a partial sheet of metallized mylar over the plexiglass tended to improve its total reflectivity.

The reflecting plates were backed by an epoxy-sand mixture to damp the plates against a standing wave being established in the plates. The backing, designed by Donaldson and Macfarlane [3], was shaped into one and one fourth inch high tetrahedrons for optimum performance. However, if the signal exceeds approximately ten volts rms, the plates still seem to cause enough reflection to cause large distortion in the received signal.

In order to maintain a standing wave between the plates, the plates must be kept rigidly parallel (maximum deviation - 2mm). Therefore, the design of the frame was critical to the operation of the standing wave system. While the frame must be sturdy enough to hold the plates parallel, it must not expose an appreciable reflecting area to the acoustic field being generated. The final design of the frame is shown in Figure 6. Sections of the frame located behind the plates out of the

acoustic field were constructed of slotted angle iron. Where the angle iron extended beyond the circumference of the plates, rubber was applied to reduce any reflections. Flat iron bars (one fourth inch thickness) were used to maintain the separation of the plates. A coil spring shock absorber was designed to protect the system from sharp jerks when used from a boat at sea. Plate alignment was accomplished by adjusting four mounting bolts equally spaced around the circumference of the plates. Optimum plate spacing (45 cm) was determined by Donaldson and Macfarlane [3] so that sound loss by diffraction was compromised with sound loss by absorption at the reflecting plates.

E. HYDROPHONE

A one fourth inch long, one fourth inch diameter barium-titanate ceramic cylinder was used as a hydrophone [4]. It was mounted through the back of the plexiglass plate and extended through the plate far enough to be flush with the reflecting side of the plate. The probe was then held in place by silicon rubber. By not extending the probe into the acoustic field, averaging of the received signal over the length of the hydrophone is avoided and scattering from the probe was minimized.

F. PREAMPLIFIER

Since the hydrophone is a very low magnitude signal and it must travel through 100 feet of coaxial cable to the amplifier, a high input impedance-low output impedance preamplifier was used near the hydrophone to improve the signal-to-noise ratio. An NUS model 2010-30 preamplifier was used. It provided 30 db. gain and was small enough to provide easy mounting. The preamplifier was clamped to the frame behind the plexiglass plate approximately one foot from the hydrophone. To protect the preamplifier from sea water, it was placed in a copper tube,

sealed and then the entire container was encased in epoxy to insure that it was watertight and electrically insulated.

G. AMPLIFIER AND RECORDER

An HP 466A amplifier was used to provide a usable signal level for the recorder. It provides gains of 20 or 40 db., has a wide frequency range, stability, and low distortion. A B&K model 2305 voltage level recorder was used to directly record the system response. When making a run, the initial and final frequencies were recorded from the frequency counter, and the time of the sweep was determined by measuring the length of recording paper used. From these three measurements, the sweep rate was calculated, and subsequently the paper tapes could be calibrated in terms of frequency. Using this method, bandwidths could be measured within ± 10 HZ for well formed resonant peaks.

VI. EQUIPMENT EVALUATION

Although the basic design of the standing-wave system described in Section V had been constructed in a previous project [3], no evaluation of the system was possible because of equipment failures. In this project, the causes of equipment failure were eliminated to enable evaluation tests to be conducted.

Leakage of water into the transducer was found to be the most common cause of failure. Besides causing the metal film to separate from the mylar, the water caused a short circuit between the two plates of the transducers. This was especially critical when using the steel plate for one electrode, since the slightest water penetration could short the two plates.

In addition, when using the steel plate as one electrode, there was a very large electrical signal present which tended to mask the acoustic signal in the system. This large electrical signal was attributed to the large area of both electrodes and the close proximity to the hydrophone. Shielding the transducer produced little improvement, nor did electrically insulating the entire steel plate and the frame to which it was attached. Because of these difficulties, a new transducer was constructed using plexiglass as the transducer backing. See Section V-D for a description of this transducer.

The electrical radiation was greatly reduced with the plexiglass transducer, providing an excellent acoustic-electrical signal ratio. An unexpected benefit was also observed during test runs of the new transducer. With the steel backed transducer, instead of a single signal peak at each resonant frequency, there were as many as four peaks

observed (Figure 7). These peaks were originally believed to be due to reflections from surfaces other than the main reflector faces, such as portions of the frame. However, with the plexiglass transducer, only two peaks were observed, and the secondary peak was of a much smaller amplitude. Although the reason for this improvement is not known with certainty, it appears probable that a portion of the signal is transmitted through the backing plates. The epoxy-sand tetrahedrons were designed to transmit this sound energy into the water instead of allowing it to reflect from the back of the plate. Because of the large acoustic impedance mismatch between the steel plate and the epoxy-sand mixture, the epoxy-sand backing lost most of its effectiveness and reflections still occurred. The plexiglass has an acoustic impedance much closer to the epoxy-sand mixture, causing higher effectiveness and weaker reflection from the back of the plate.

Tests were made of the system performance when operated under various orientations in the water. In order to determine the orientation which provided the optimum operating characteristics, four orientations of the plates were tested. The plates were first orientated parallel to the water surface, with the transducer on top, and then inverted so the transducer would be on the bottom. The plates were then tested while at right angles to the water surface and finally when the plates were angled 30 degrees from the horizontal plane.

With the transducer on the bottom, resonant bandwidths of approximately 700 Hz (frequencies 24-33 kHz) were obtained. With the plates at an 30-degree angle, bandwidths were slightly greater (800 Hz), while when the plates were positioned vertically, bandwidths of over 1100 Hz were measured. All of these resonant peaks were low magnitude, flattened peaks and rather difficult to measure due to distortion.

With the transducer placed on top, large, symmetrical peaks were recorded with bandwidths between 700 to 800 Hz. Although the bandwidths were not particularly better with this plate orientation, it was found that the bandwidths remained essentially constant with depth, although tests were limited by the depth of available tanks (eight feet). With the plates in the other orientations, the bandwidths were found to vary with depths due to the change in hydrostatic pressure. Presumably this pressure change caused a change in the spacing between the mylar and the metal plate, altering the transducer characteristics and causing larger sound absorption by the air space behind the mylar. However, when the transducer was lowered face down, the hydrostatic pressure tends to press the mylar against the metal plate. Since the mylar is already attracted tightly to the metal plate due to the polarization, the pressure changes cause very little change in operating characteristics. Therefore, all subsequent measurements were made with the transducer on top.

The system stability (its ability to produce identical results under identical conditions) was evaluated next. This evaluation consisted of a series of runs over the entire frequency range (20-100 kHz) being made over a period of 45 hours. The results were then put in graphical form for ease of analysis (Figure 8). The system Qs were found to vary during the duration of the test. The maximum variation of the 33 kHz curve would correspond to a bubble concentration of 430 bubbles/m^3 of 100 micron bubbles. This variation, although not large compared to bubble concentrations expected at sea (several thousand bubbles/m^3), was considered to be too large for calibration purposes.

Up to this time, the bubble concentration in the tank water had been considered small and relatively constant. However, due to the system

variation with time, it appeared that the tank's bubble population was large enough to affect the system's operation, possibly due to photosynthesis by fresh water micro-organisms [5]. It was found that because of the plate's orientation in the water, the upper plate would tend to collect bubbles, causing a greater affect than the actual concentration of bubbles in the tank would indicate. In order to keep the system free of this bubble build-up, a "bubble broom" was built. Sweeping the transducer face before each run, a new time evaluation was made. The results are shown in Figure 10. The curves are now seen to stabilize quickly after the system is immersed, and to remain within very narrow limits. The system Qs are also improved over the previous evaluation, showing further evidence of the elimination of bubbles. System bandwidths range between 500-700 Hz over the frequency range. Using these curves, the system's inherent error was determined to be ± 10 Hz in bandwidth corresponding to 500 bubbles/m^3 at 67 kHz. This error is due to the inability to measure the Q curves closer than ± .1 mm.

Because of the effect of the tank bubbles on the system, a re-evaluation of the polarization was made. Previous investigators believed that the mylar characteristics changed with time when a DC voltage was applied. This change had been attributed to a slow polarization of the mylar transducer [4]. Donaldson and Macfarlene [3] designed a switching network which would alternately apply positive and negative polarizing voltages to the transducer in an attempt to operate with a constant output.

This alternating-polarization system was initially used in this project. However, it was found to be unsatisfactory due to the long charge time of the mylar transducer. The transducer charge time was found to be about ten seconds (Figure 9), while the lowest frequency at which

the switching network could be operated was about ten Hz. Therefore, the transducer was constantly being operated with the transducer undergoing rapid charging. Since the system characteristics change while the transducer is charging, the alternating polarization system was deemed unsatisfactory for this system. Instead, the polarization was manually switched before each run, allowed to charge to a stable level, and then a new run was started. In this manner, the transducer was constantly being operated with the same time of polarization.

However, due to the effect of bubbles in the tank, a new evaluation of the effect of a continuous polarization was made to determine if the changes mentioned above were actually due to changes in the transducer characteristics or due to bubbles. Runs were made over an eight hour period with constant polarization. The plates were swept before each run to remove any bubble accumulations. There was no change observed in the system Qs or in the output level.

Therefore, it was concluded that a continuous polarization applied to the transducer would have no adverse effect on its performance. However, the magnitude of the polarizing voltage was found to be very critical. A decrease of 15 VDC was found to cause as much as 100 Hz change in bandwidth. As small a change as four VDC still causes up to a 50 Hz change in bandwidth. Therefore, the polarization must be kept within about ± 1 volt DC in order to insure consistant results.

In order to test the system's ability to measure bubble concentrations, bubbles were allowed to accumulate within the system. Runs were then made with the bubbles present. The bandwidths were determined and compared with bandwidths measured when the plates had been swept free of bubbles. The results are tabulated in Table 3.

VII. GENERAL CONCLUSIONS

A. SUMMARY

Although the standing wave system has not been evaluated under operating conditions at sea, tests conducted in this project indicate that the standing wave system is a practical and dependable instrument for bubble measurements at sea. The system error of $\pm$ 10 Hz in bandwidth is well within the limits which can be tolerated in actual measurements. The frequency range with which this instrument can be operated (20-100 kHz) is not as broad as desired. However, further research into the operating characteristics of the standing wave system may provide the answer to this problem.

The following characteristics were determined experimentally:

1. System responses were able to be analyzed over the entire frequency range.

2. Best system responses were bandwidths on the order of 500-600 Hz (maximum Q = 150) using the plexiglass backed transducer.

3. The plexiglass backed transducer provided less distortion in the system response.

4. System characteristics do not change with time when a constant DC voltage is applied. System response does change if polarization varies in magnitude.

5. Best system response was obtained with the transducer operated over the reflector.

B. RECOMMENDATIONS:

1. Conduct calibration runs of the system in a tank fitted with dust covers and filled with chemically treated water to kill algae in order to reduce bubble formation in the tank.

2. Design a suspension system for the instrument so that it will remain stationary in the water column and not be affected by the rolling of a research boat.

3. Investigate the possibility of battery power for the electronic components in the system in order to reduce ship noises affecting the system operation.

4. When constructing a transducer of the design used in this project, insure that the mylar sheet is cut back away from all sharp edges. This provides a more secure bond for the epoxy to prevent water leakage. Also insure that the epoxy layer is thick enough to provide protection but not too thick to hinder the transducer operation. A one mm thickness was found to be satisfactory.

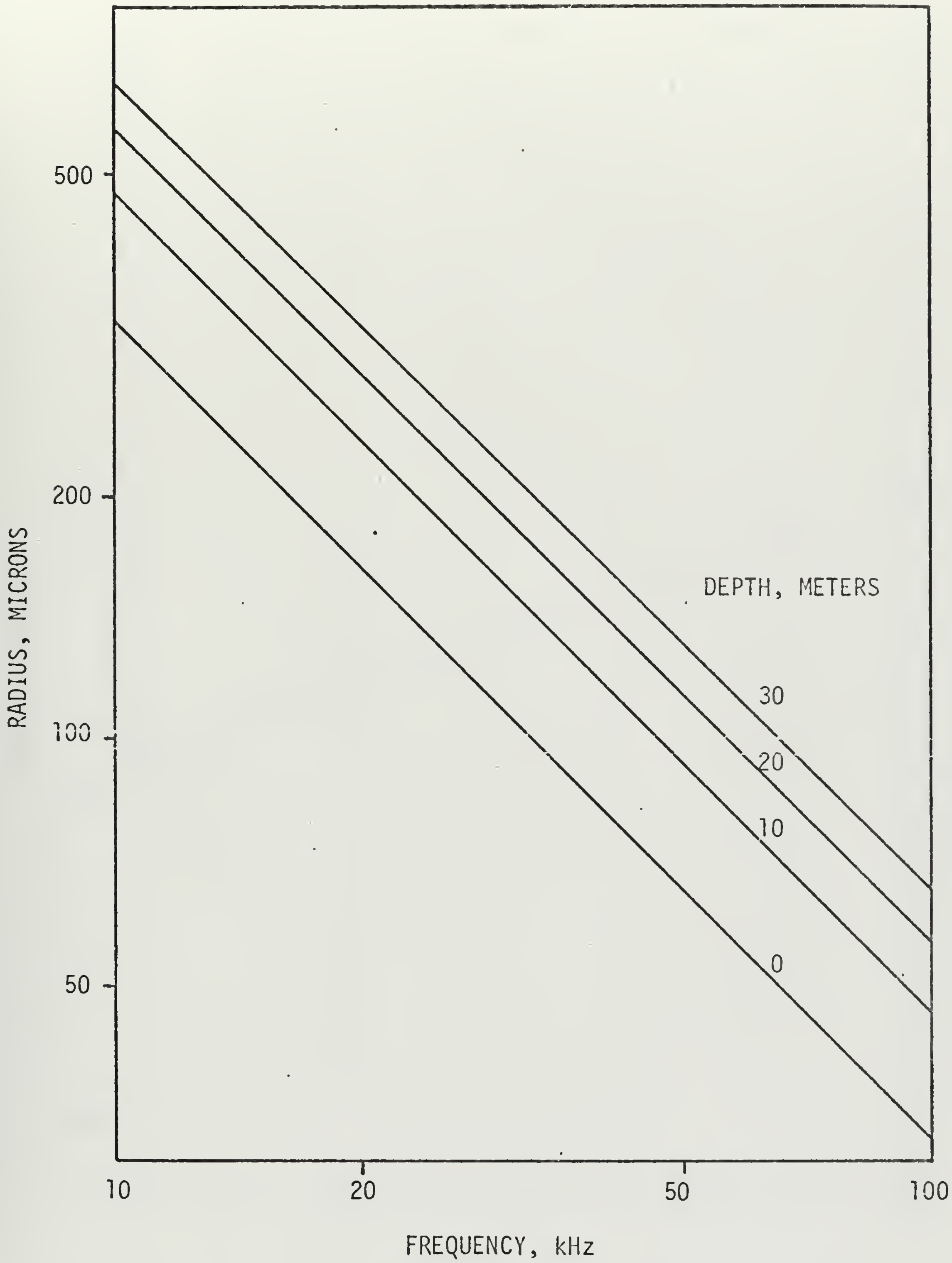

Figure 1. Bubble Radius as a Function of Resonant Frequency and Depth for Airfilled Bubbles (3).

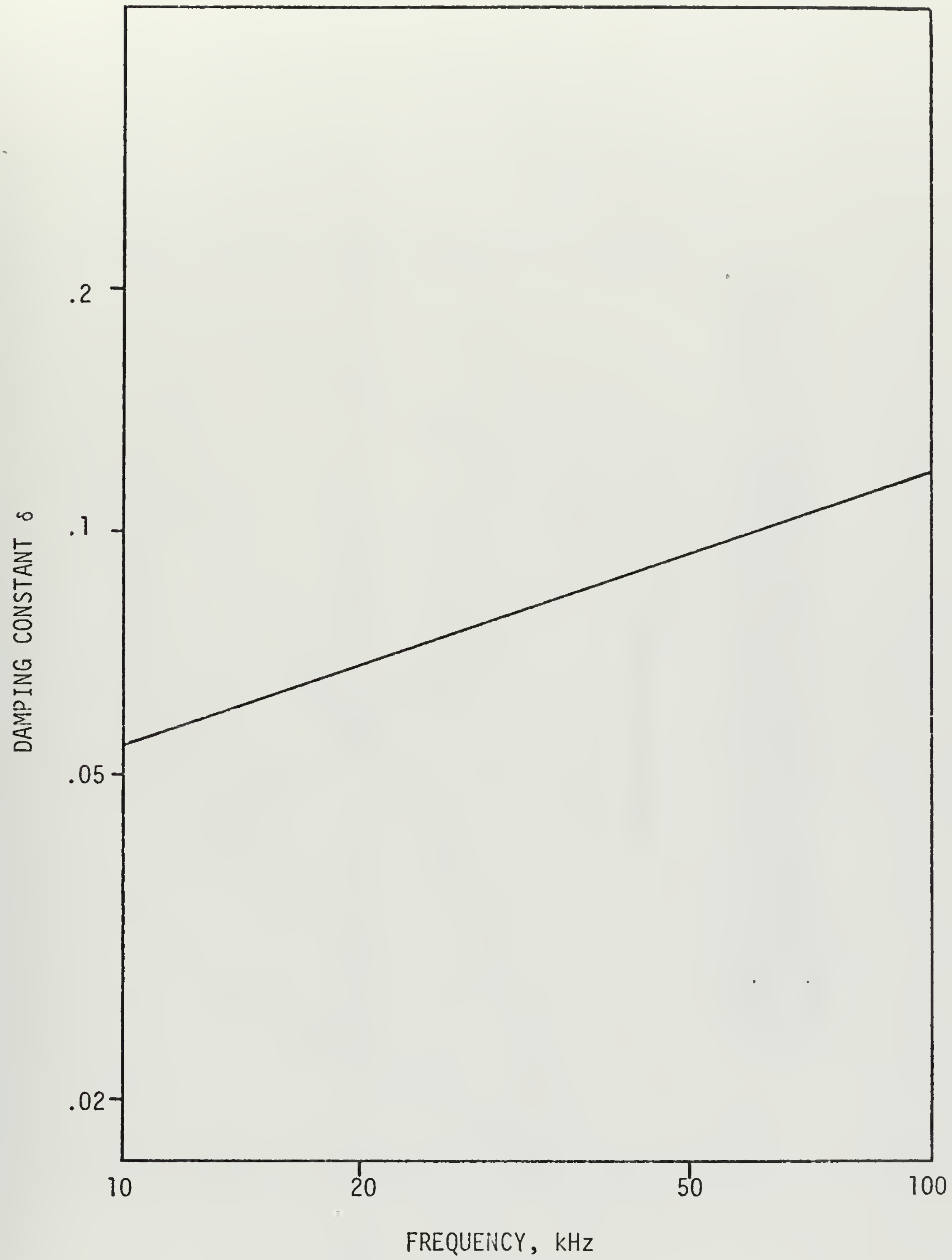

Figure 2. Damping Constant as a Function of Frequency (3).

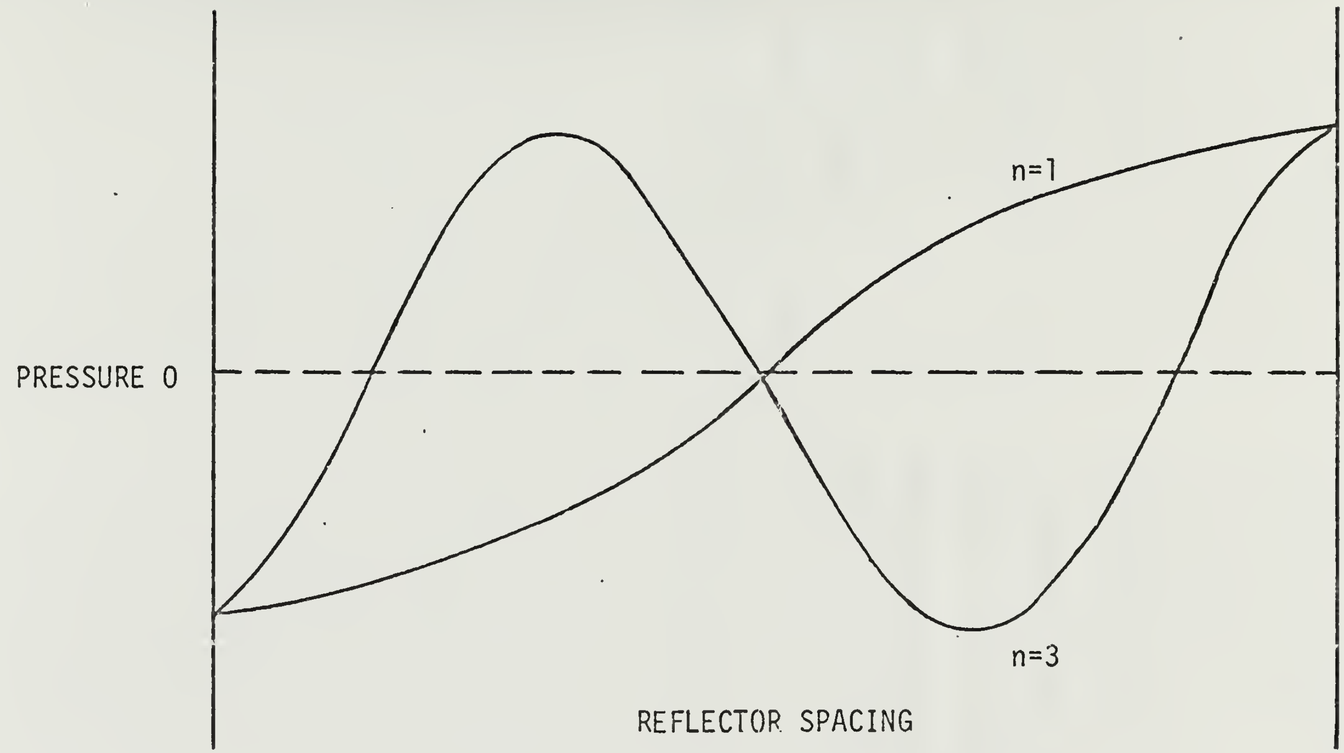

Figure 3. Diagram of Pressure Amplitude in Two of the Standing Wave Modes Between Two Rigid, Parallel Reflectors, n=1, n=3 (n = an integer multiple of a half wavelength for a given frequency).

TABLE I. SYSTEM ELECTRONICS

Signal Generator	Hewlett Packard 3590A Wave Analyzer
Power Amplifier	Hewlett Packard 467A Power Amplifier
Polarization	300 Volt Battery
Transducer	See Figure 6
Hydrophone	One Fourth Inch Barium Titanate Hollow Cylinder
Preamplifier	NUS Model 2010-30 (30db gain)
Amplifier	Hewlett Packard 466A AC Amplifier
Recorder	B&K Type Voltage Level Recorder
Oscilloscope	Tektronix Type 545 Oscilloscope
12 Volt Power Supply	

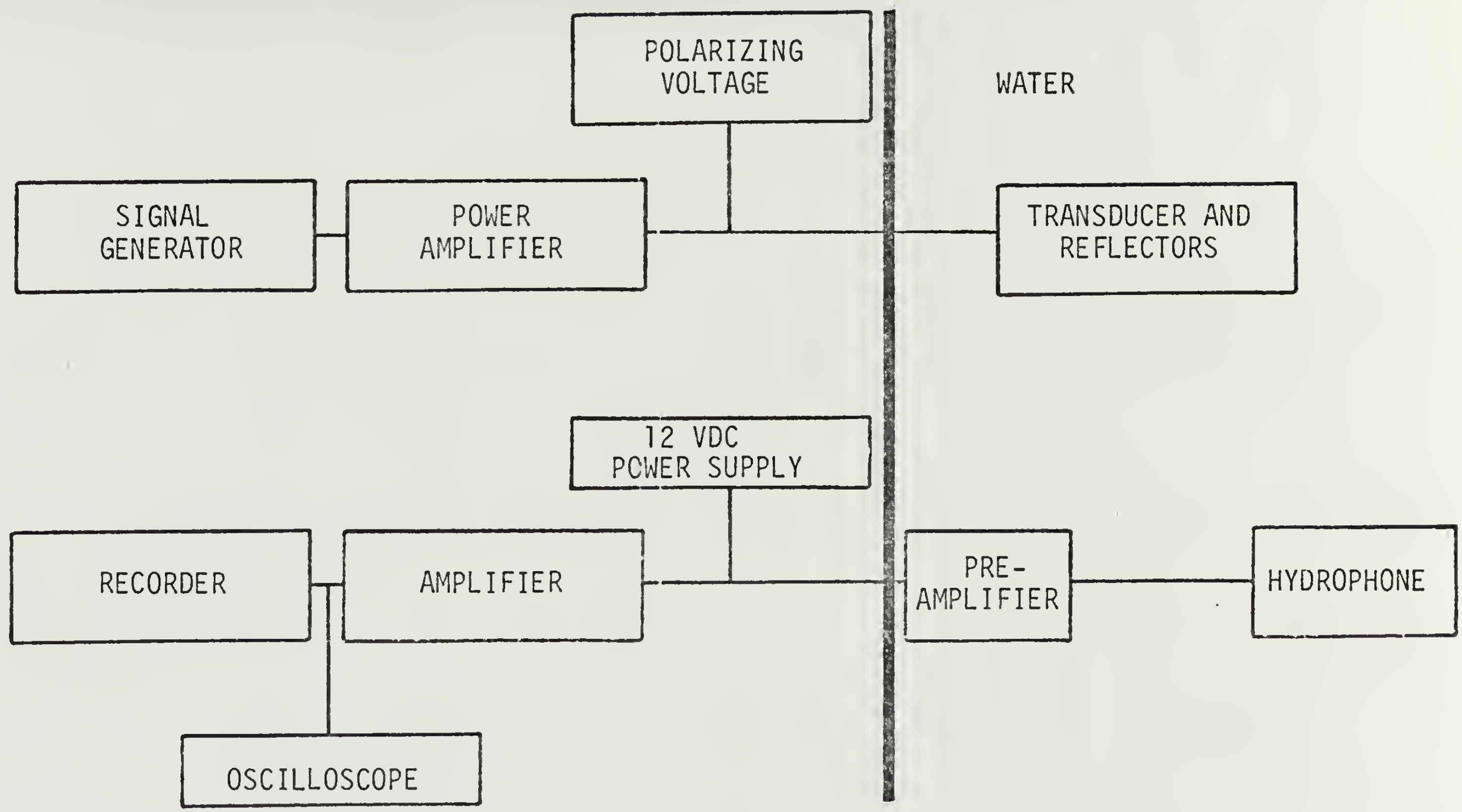

Figure 4. Block Diagram of Standing Wave System.

TABLE II. TRANSDUCER SPECIFICATIONS

Plate Diameter	30 Inches
Plate Thickness	1 Inch
Annular Ring o.d.	26 Inches
Annular Ring i.d.	18 Inches
Air Slot	1/2 Inch by 1/2 Inch
Pickup Access Diameter	1/2 Inch
Tetrahedron Backing Thickness	1-1/4 Inch
Transducer Capacitance	.1 μf

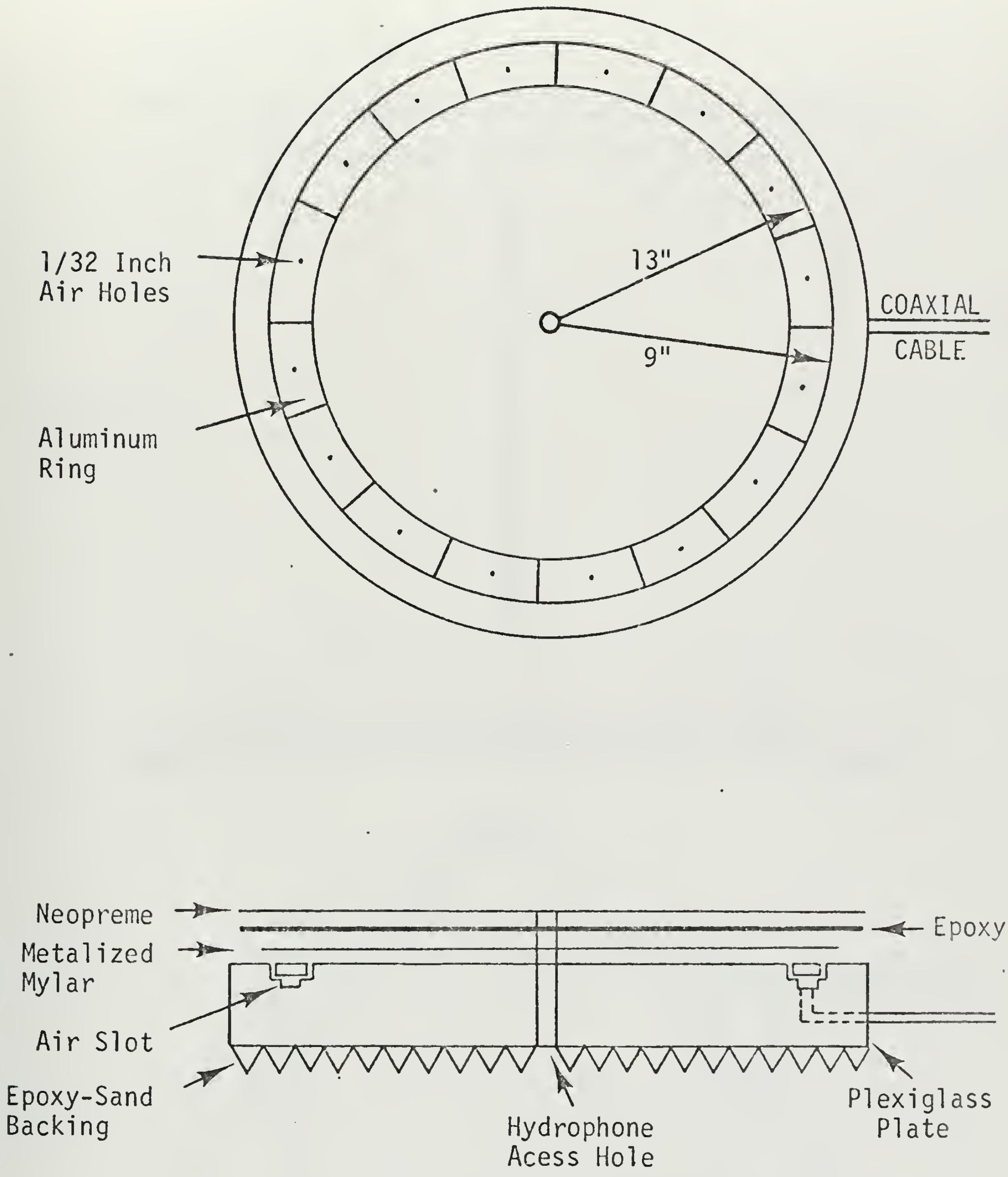

Figure 5. Transducer Diagram.

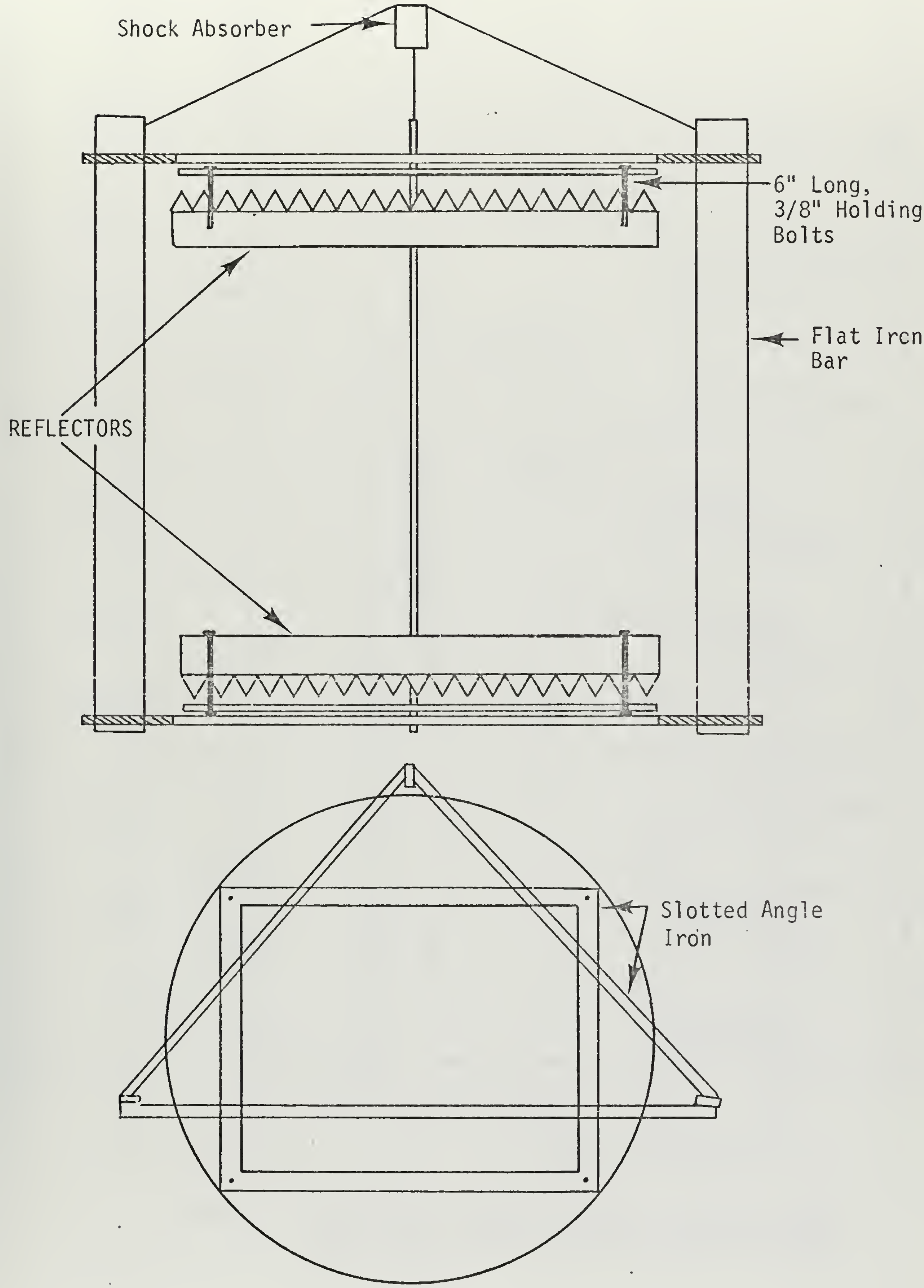

Figure 6. Diagram of Frame with Plates.

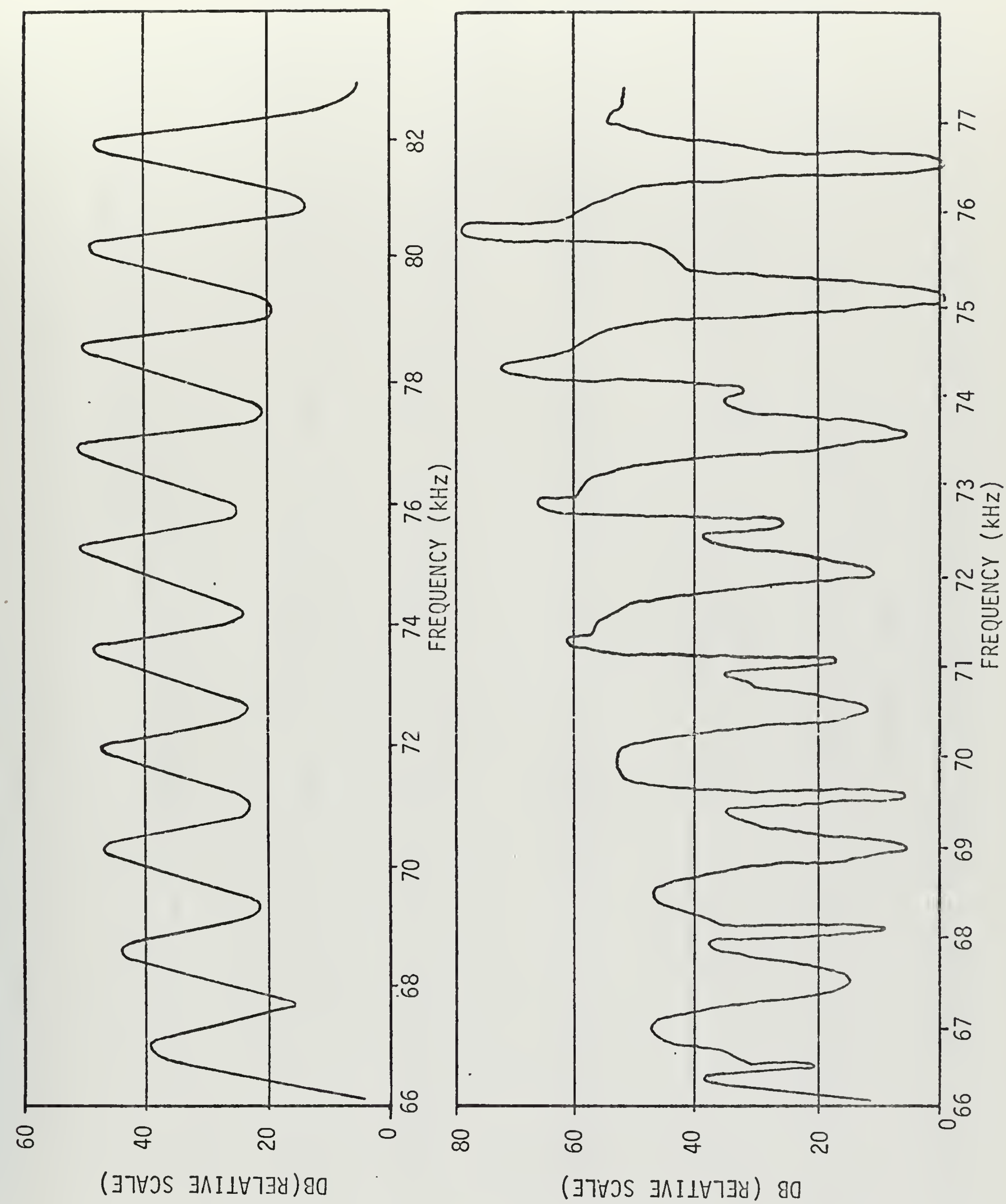

Figure 7. Sample's of System Response for Two Transducer Backs-Top: Plexiglass Plate; Bottom: Steel Plate.

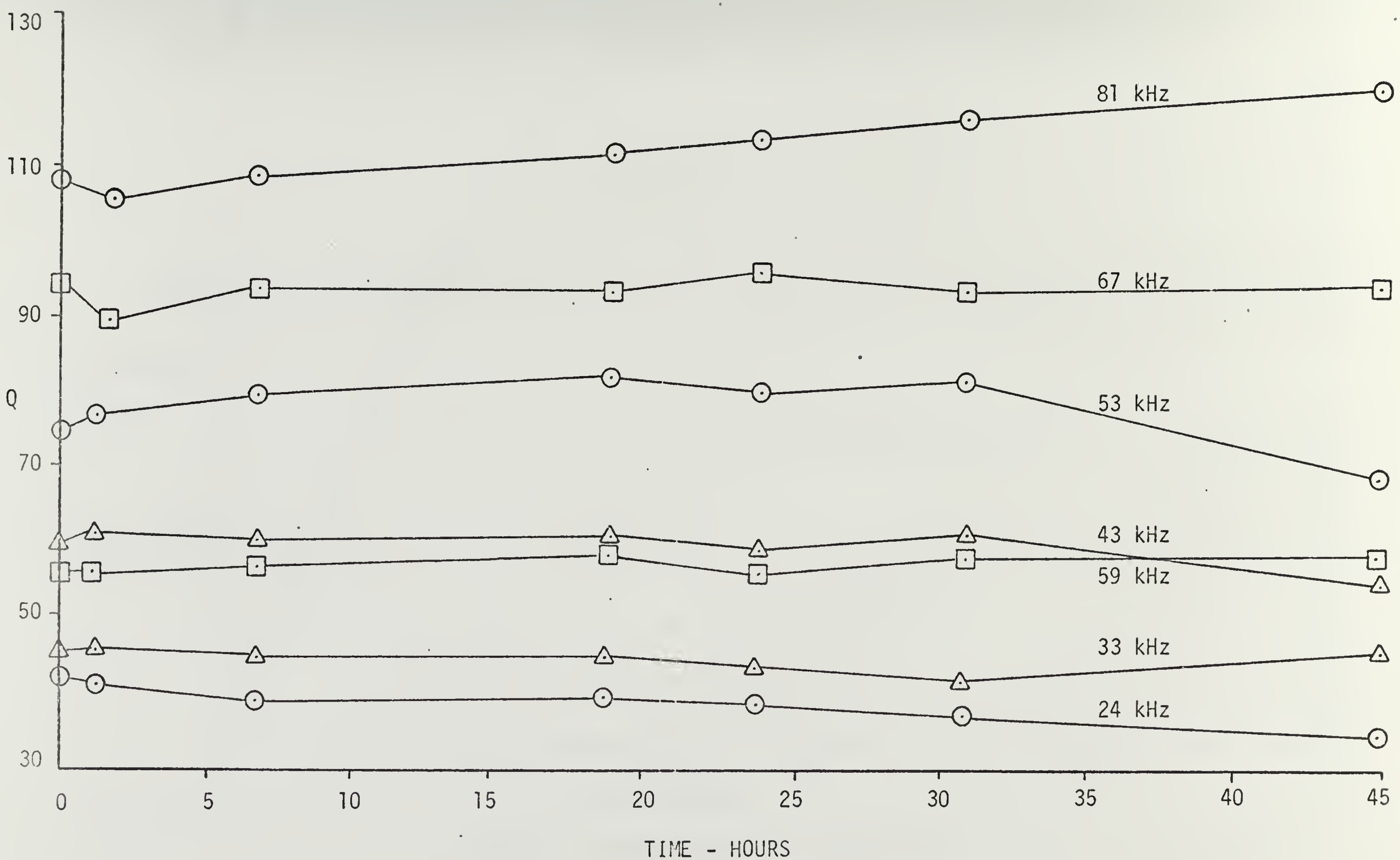

Figure 8. Time versus Q Curves for Plexiglass Transducer. No Bubble Removal.

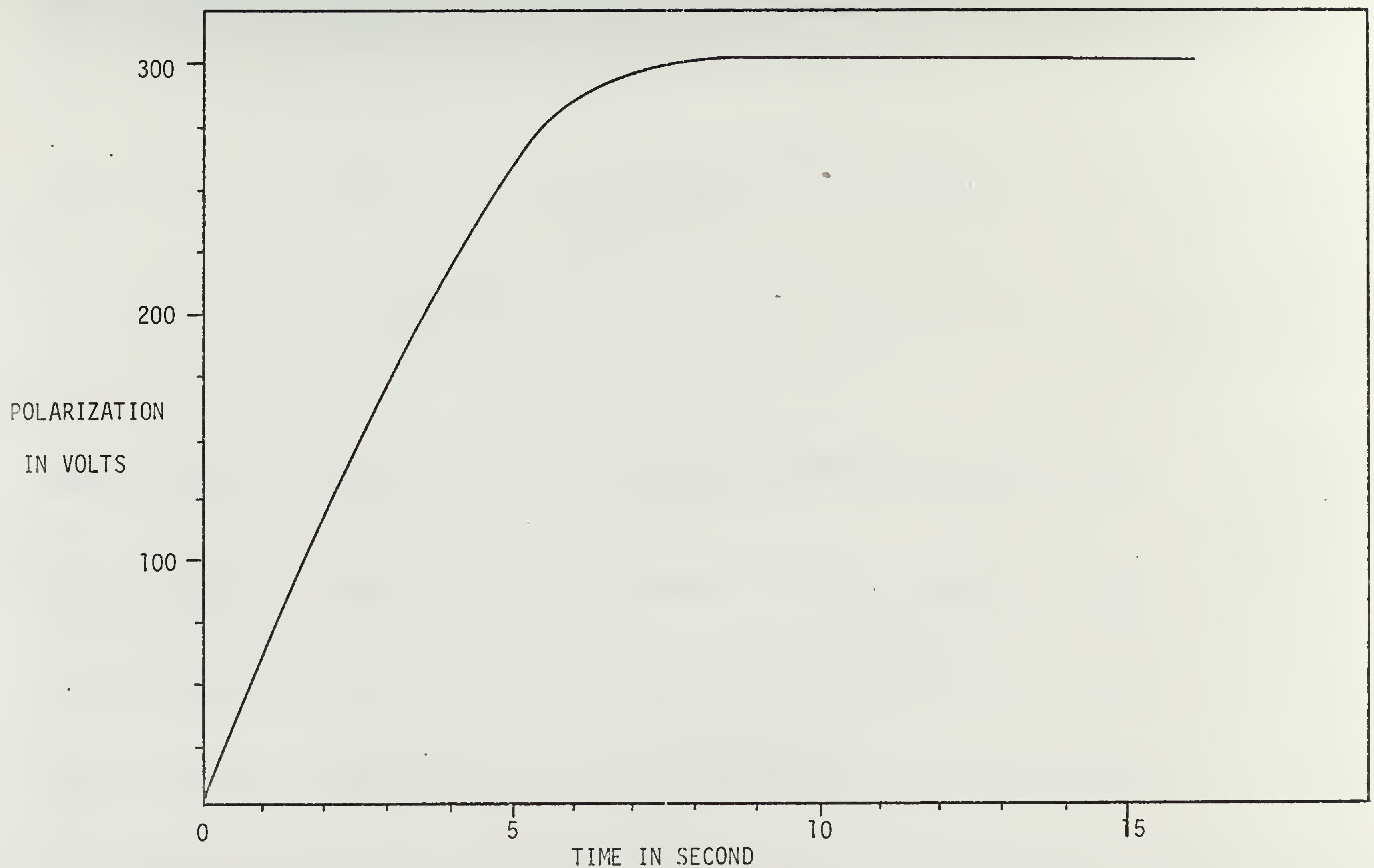

Figure 9. Charging Curve of Transducer.

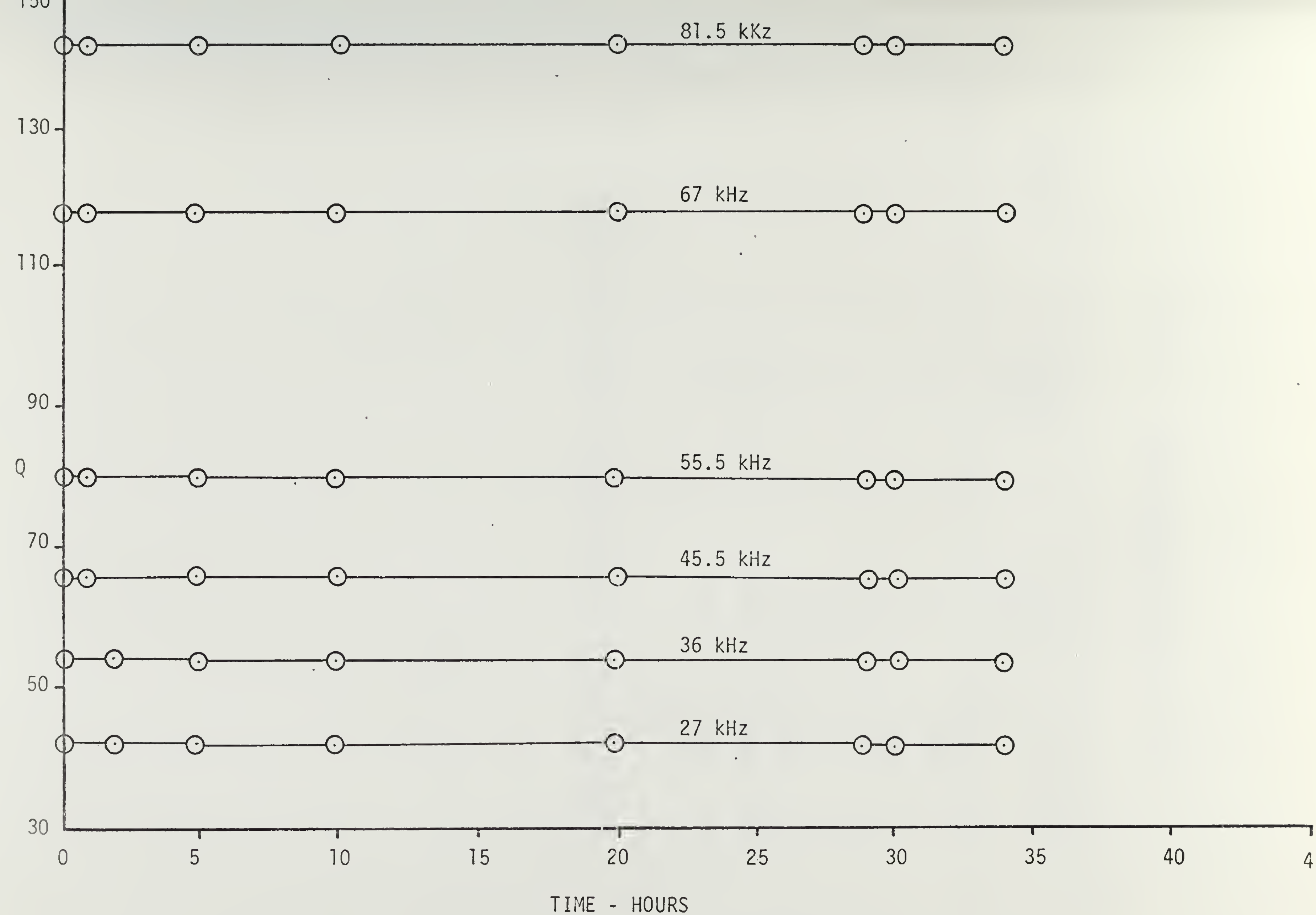

Figure 10. Time versus Q for Plexiglass Transducer. Bubbles Removed.

TABLE III. BUBBLE CONCENTRATIONS MEASURED IN A LABORATORY TANK*

FREQUENCY kHz	BANDWIDTH WITHOUT BUBBLES	BANDWIDTH WITH BUBBLES	BUBBLES/m^3
27	686	705	66.8 ± 34
36	667	700	193 ± 59
45.5	687	742	622 ± 114
55.5	696	763	1190 ± 180
67	568	700	3700 ± 500
81.5	576	666	6850 ± 1140

* Bubbles measurements are higher than actual tank bubble concentrations due to bubble accumulation on upper plate.

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Development and Testing of an Acoustic System for In Situ Determination of Microbubble Concentrations in the Ocean.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; June 1971

5. AUTHOR(S) (First name, middle initial, last name)

Leonard A. Wiens

6. REPORT DATE June 1971	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

The effect of bubbles on sound propagation in the ocean has long been known. More recently, bubbles rising to the ocean surface have been related to salt nuclei in clouds. Yet due to the lack of suitable instrumentation little data are available on the concentration of bubbles in the ocean. A one-dimensional standing wave system was constructed and evaluated to determine bubble concentrations by measuring the effect of bubbles on the system damping constant (Q^{-1}). The system was comprised of a mylar electrostatic transducer built into a plane reflector facing a parallel reflecting plate, and associated electronic components. The system was designed to measure bubbles of radius from approximately 500 microns to 30 microns utilizing frequencies from 20 to 100 kHz at depths to 30 meters. The system accuracy was determined to be $\pm$ 10Hz in resonant bandwidth corresponding to 500 bubbles/m^3 at 67 kHz. The system was used to successfully measure bubbles in a laboratory tank.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31438

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Acoustic						
Microbubbles						
Resonance						
Standing Wave						

128620
Thesis
W5825 Wiens
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